THE INTRARENAL PRESSURE

Its Relation to Age, Weight, Blood Pressure, and Sex*

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By the use of a new method for measuring the intrarenal pressure, we have shown it to be about 26 mm. Hg in decerebrate dogs (1, 2). It is the purpose of the present report to amplify this series and also to give data obtained on unanesthetized normal dogs and on dogs under sodium pentobarbital anesthesia. The relation between the intrarenal pressure and the age, weight, blood pressure, and sex of the dogs was also ascertained. A few measurements of the IRP in cats, rabbits, and rats will also be reported.

Methods

The intrarenal pressure is measured (2) by thrusting deep into the medulla of the kidney a perforated 20-gauge needle, which is connected with a manometer. 250 mm. Hg is then suddenly imposed on the system. The elasticity of the manometer, etc., rapidly forces a small amount (about 10 c. mm.) of saline-heparin into the kidney until equilibrium is reached with the pressure of fluids in the kidney tissue. The pressure changes are recorded; when no further change in pressure is registered, this is the objective measurement of intrarenal pressure (to be abbreviated henceforth as IRP).

The IRP was measured three times in each dog, the mean of the three measurements being given in these data. Readings were taken immediately after the kidney was exposed with care to avoid manipulation of the kidney and trauma. Systolic and diastolic blood pressures were taken simultaneously by optical means with a glass Bourdon tube (3, 4), after cannulation of the femoral or carotid artery. Dogs 1 year old or over were used, the age being estimated from the teeth wear by Boenish's (5) method. The decerebrated dogs were prepared as described by Fee (6); the IRP of these animals was taken after the animal had breathed off the ether employed during the surgical procedure, at a time when the animal's spinal reflexes had returned. In the experiments with unanesthetized dogs, explantation of the kidney to a subcutaneous position in the flank, with excision of the contralateral kidney was accomplished, following in general the technic of Rhoads (7). About 15 days afterwards, observations of IRP were taken. With the kidney explanted, measurements of IRP were readily taken by thrusting the needle through the skin and into the kidney. The dogs were trained to lie still; they were neither hurt nor excited during the procedure.

In order to determine whether different species of animals would have the same magnitude of IRP as dogs, measurements were also made on cats, rabbits, and rats. All were anesthetized with sodium pentobarbital.

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TABLE I

Intrarenal Pressure of Anesthetized Dogs

Dog	IRP	Sex	Estimated age	Weight	Blood pressure
No.	*mm. Hg*		*yrs.*	*kg.*	*mm. Hg*
1	33	M	2½	9.0	178/130
2	47	F	10–12	16.0	161/106
3	12	M	2½		90/62
4	13	F	2	6.6	154/120
5	39	F		9.7	150/118
6	12	F	2	5.3	150/108
7	30	F	1½	5.6	138/104
8	21	F	5	13.6	183/111
9	28	M	10	8.8	140/92
10	21	M	1	9.8	181/130
11	20	M	1½	5.7	140/118
12	24	F	1	6.0	136/97
13	17	M	1½	13.0	130/105
14	37	F	3	16.9	142/115
15	24	M	1½	9.7	186/132
16	16	F	2	8.9	157/100
17	29	F	4½	10.5	150/122
18	36	F	1½	11.8	150/85
19	17	F	1	4.5	155/120
20	22				140/103
21	13	M	1	6.0	150/120
22	21	M	7		195/146
23	35	F	3½	12.5	168/140
24	31	M	1	10.0	164/138
25	20	F	2½	11.5	180/130
26	33	M	1½		165/120
27	24	M	1½	8.8	
28	25	F	1½	9.1	107/45
29	36	F	2	12.5	160/96
30	14	F	1½	9.0	162/150
31	15	M	1½	7.0	130/58
32	35	F	2	10.5	140/110
33	58	M	3	18.0	160/140
34	18	M	3	9.5	184/145
35	10	M	1½	6.0	140/110
36	58	M	2	15.0	168/128
37	23	F	15	16.0	162/97
38	10	F	1½	5.3	158/108
39	33	M		7.5	142/110
40	25			12.7	172/108
41	33	M	2½	7.0	158/114
42	30	F	1½	9.8	194/130

RESULTS

In Table I are shown the intrarenal pressures of 42 dogs anesthetized with sodium pentobarbital. Their sex, estimated age, weight, and blood pressure are also shown. Table II shows that the mean IRP of these dogs was 26 mm. Hg. Other statistical measures of the variance in the group are shown in the table. The IRP for 16 decerebrate dogs was found to be, respectively, in mm. Hg, 27, 23, 21, 25, 15, 35, 35, 22, 25, 33, 28, 30, 13, 26, 30, and 18. The IRP for 9 unanesthetized dogs with explanted kidneys was found to be, respectively, in mm. Hg, 27, 35, 23, 34, 25, 16, 25, 22, and 21. Table II shows that the means for these two types of preparation were 25 and 25 mm. Hg respectively.

TABLE II

Intrarenal Pressures of Groups of Dogs

	Number of dogs	Mean	Standard deviation	Standard error	Range
		mm. Hg	*mm. Hg*	*mm. Hg*	*mm. Hg*
Sodium pentobarbital	42	26	11.0	1.7	10–58
Decerebrate	16	25	6.4	1.6	13–35
Normal, unanesthetized, (explanted kidney)	9	25	5.7	2.0	16–35

TABLE III

Relation of Intrarenal Pressure to Other Variants

	Coefficient of correlation (*r*)	Standard error of *r*	*P*
Age	.20	.16	.20
Body weight	.54	.12	.000008
Kidney weight	.54	.17	.0007
Blood pressures:			
Diastolic	.30	.15	.04
Systolic	.13	.17	.56
Average	.28	.16	.08

Table III shows the correlations of the IRP of the anesthetized dogs with age, body and kidney weight, and blood pressure. Correlation with age is almost nil—a coefficient of correlation of .20. The correlations with body weight and kidney weight are both .54; these are significant correlations in the statistical sense but the relation is not very clear cut. As the table indicates, there is virtually no relation between the IRP and the systolic or diastolic or average blood pressure of the normal anesthetized dog. Finally, no difference between the IRP of male and female dogs was observed: the average of the males was 27 mm. Hg and that of the females was 25 mm., the standard errors of these two means being, respectively 3.27 and 2.34.

The mean IRP of 4 pentobarbitalized cats was 32 mm. Hg, the individual readings being 31, 42, 16, and 39 mm. The mean IRP of 4 pentobarbitalized rabbits was 19 mm., the individual readings being 19, 17, 19, and 20 mm. In rats, employing the same technics, no satisfactory measurements of IRP were obtained. Customarily, the IRP was found to be 0; even when a small 27 gauge needle was employed, no pressure inside the renal parenchyma was found. It is apparent that the present technic gives us little information about the rats' intrarenal pressure.

DISCUSSION

The intrarenal pressure is now generally taken to be about 10 mm. Hg. This figure stems from Winton's experiments (8). He employed an indirect approach to the problem: using the isolated perfused kidney, he found that either ureteral or renal venous pressure could be increased to about 10 mm. Hg before urine flow was appreciably decreased. Winton reasoned that these observations could best be explained by assuming that there is an intrarenal pressure of 10 mm. Hg which under normal circumstances keeps some part of the tubules collapsed. In order for urine to pass through the tubules, the hydrostatic pressure of the urine gradually increases until it exceeds the collapsing pressure.

The value of 10 mm. Hg for intrarenal pressure we consider to be far too low, because we have now obtained values of about 26 mm. Hg. by three different methods (1, 2) in dogs. In the first place, when pressure is imposed upon a microcannula set in the renal parenchyma, it has been demonstrated that flow of fluid into the parenchyma stops when the pressure within the cannula falls to 26 mm. Hg (2); and in the second place it has been shown by two different methods that the kidney forces fluid out of such a cannula spontaneously at pressures of about 26 mm. (1, 2). Furthermore, in two other species, cats and rabbits, the IRP is the same in magnitude as in dogs. The fact that Winton was employing isolated blood-perfused kidneys may account for the lowness of his estimation of the IRP.

A tissue pressure of 26 mm. Hg is very high when compared with tissue pressures elsewhere in the body. It is some ten times greater than intradermal interstitial pressures (9), some eight times greater than intramuscular pressures (10, 11), and some ten times greater than intracortical pressures (2). This situation raises several interesting problems with respect to the dynamics of fluid flows in the kidney. It appears to us likely that in order for fluids to flow in and through the renal parenchyma, their pressure must exceed 26 mm. Hg. Thus, tubular urine, venular blood, and even lymph must, in the kidneys, all be under a pressure greater than 26 mm. Hg. Furthermore, as will be subsequently shown, during sugar diuresis while under anesthesia, the IRP often increases to about 60 mm. Hg. Again, for flows of urine, venous blood, or lymph to take place out of such a kidney, they must be under pressures greater than 60 mm. Hg or else the IRP would collapse and block the thin walled vessels involved.

It is not difficult to comprehend that the average intratubular pressure may be greater than 26 mm. Hg, since it has long been recognized (see reference 8) that urine is still formed when the ureteral pressure, which is presumably transmitted back to the tubules, is greater than 26 mm.; that is, urine flow does not cease until the ureteral pressure is about 30 mm. Hg. Furthermore, during diuresis, many (see reference 8) have found that the "maximum ureteral pressure" is 70 mm. Hg—a figure even greater than the IRP of 60 that we have found for diuresis in the anesthetized dog. Intratubular pressures of 30 or even 60 mm. Hg, then, are not hard to understand. However, the proposition that the intravenular and intralymphatic pressures must exceed 26 mm. Hg or, in some circumstances, 60 mm. Hg, is a difficult one to support. The venular pressure is classically thought to be some 5 to 10 mm. Hg, the hydrostatic pressure dropping from 40 to 10 as blood flows from the arterial end to the venous end of the capillary loop. The tissue hydrostatic pressure is generally thought to be 3 to 10 mm. Hg; but if it were 26 mm., no circulation from the blood to the tissue fluids would occur because the effluent hydrostatic and oncotic forces would be completely overborn by the influent hydrostatic and oncotic pressures. And if the tissue pressure were 60, presumably blood would never even reach the capillaries. The resolution of this difficult proposition and of the elusive source of these high pressures will be attempted in subsequent papers. It is sufficient to point out here that the kidney will indeed form urine even though the renal venous pressure is raised to 30 mm. Hg (12).

The method here employed of estimating the age of a dog by the wear of its teeth is very poor, being often grossly erroneous. But even so, if there were a relation between the age and IRP, some statistical correlation, even though poor, should have been found. But the coefficient of correlation, r, was only .20, with a standard error of .16, thus failing to show any relation to age. This conclusion must remain tentative until more adequate data on dogs' ages are obtained.

SUMMARY

1. The intrarenal pressure of dogs anesthetized with pentobarbital averages 26 mm. Hg, and ranges from 10 to 58 mm.; that of decerebrate dogs is 25 mm., and that of unanesthetized dogs with explanted kidneys is 25 mm. Tests of a few cats and rabbits indicate that their intrarenal pressure has about the same magnitude.

2. There is a slight positive correlation between intrarenal pressure and

both body weight and kidney weight, but intrarenal pressure is not related to sex, blood pressure, or age.

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